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Cervical spine trauma – Evaluating the diagnostic power of CT, MRI, X-Ray and LODOX

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ABSTRACT

Background: Traumatic cervical spine (c-spine) injuries account for 10% of all spinal injuries. The c-spine is prone to injury by blunt acceleration/deceleration traumas. The Canadian C-Spine rule and NEXUS criteria guide clinical decision-making but lack consensus on imaging modality when necessary. This study aims to evaluate the sensitivity and specificity of CT, MRI, X-Ray, and, for the first time, LODOX-Statscan in identifying c-spine injuries in patients with blunt trauma and neck pain.

Methods: We conducted a retrospective monocenter cohort study using patient data from the emergency department at Inselspital, Bern, Switzerland's largest level one trauma center. We identified patients presenting with trauma and neck pain during the recruitment period from 01.01.2012 to 31.12.2017. We included all patients that required a radiographic c-spine evaluation according to the NEXUS criteria. Certified spine surgeons reviewed each case, analyzed patient demographics, injury classification, trauma mechanism, and emergency management. The retrospective full case review was established as gold standard to decide whether the c-spine was injured. Sensitivity and specificity were calculated for CT, MRI, LODOX, and X-Ray imaging methods.

Results: We identified 4996 patients, of which 2321 met the inclusion criteria. 91.3% (n = 2120) patients received a CT scan, 8.9% (n = 206) a MRI, 9.3% (n = 215) an X-ray, and 21.5% (n = 498) a LODOX scan. By retrospective case review, 186 participants were classified as injured. The sensitivity of CT was 88.6% (specificity 99%), and 89.8% (specificity 99.2%) with orthopedic surgeon consultation. MRI had a sensitivity of 88.5% (specificity of 96.9%); highlighting 14 cases correctly diagnosed as injured by MRI and misdiagnosed by CT. Projection radiography (36.4% sensitivity, 95.1% specificity) and LODOX (5.3% sensitivity, 100% specificity) were unsuitable for ruling out spinal injury.

Conclusion: While CT offers high sensitivity for detecting traumatic c-spine injury, MRI holds clinical significance in revealing injuries not recognized by CT in symptomatic patients. LODOX and projection radiography are insufficient for accurately ruling out c-spine injury. For patients with neurological symptoms, we recommend extended MRI use when CT scans are negative.

Introduction

Traumatic cervical spine injuries account for 10% of all spine injuries. With 40% of all cervical spine injuries involving the *Atlas* (C1) and *Axis* (C2), the majority of cervical spine (c-spine) injury resides in the lower part (1,2). The cervical spine is prone for traumatic injury and main causes for c-spine injury are blunt acceleration/deceleration traumas (e.g., falls, vehicle crashes, alpine sports accidents), commonly referred to as Whiplash injury with reported cumulative annual incidences up to 3/1000 inhabitants per year in the US and Western Europe (3-5).

In clinical management, the Canadian C-Spine rule (CCR) (6) and National Emergency X-Radiography Utilization Study (NEXUS) (7) criteria provide the basis of clinical decision-making over the past

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decades. Profiting from a sensitivity of up to 90%, both scores are highly valuable in ruling out cervical spine injury (8). However, in the emergency department, there is no clear consensus on which imaging modality to choose when imaging is necessary. Moreover, low specificity and false positive criteria in both CCR and NEXUS (8) lead to a lot of potentially unnecessary imaging (8). The ATLS® (9) manual does not specify any preferred imaging technique (10) while in clinical practice multi-detector computer tomography (CT) and magnet resonance imaging (MRI) play a key role in correctly assessing spine patients (11). Especially in young patients, emergency physicians are committed to achieving the least radiological exposure and fast results, favoring the acquisition of X-rays. However, the reported sensitivity for plain radiographs to detect spinal injuries is unclear between 33 and 93% (12-20). Studies investigating the sensitivity and specificity of CT scans and MRI have reported up to 100% sensitivity for CT scans (21,22). However, our clinical experience has revealed instances of patients with preexisting degeneration of the cervical spine who suffer from central cord syndrome and exhibit negative CT scans. These patients benefit from early decompression, and our standard operating procedure mandates an early MRI in such cases. Given that the widely cited literature may overestimate the sensitivity of CT scans, we aim to present our data to provide a more accurate understanding.

In this study, we evaluate the sensitivity and specificity of conventional projection radiography, LODOX, MRI, and CT to identify cervical spine injury in patients that presented with blunt trauma and neck pain and were not ruled out by the NEXUS criteria.

Material and methods

Study design and setting

This study design is a monocenter retrospective cohort study. All patients were admitted and treated at the emergency department of Inselspital, Bern University Hospital, Switzerland. It is the largest level one trauma-center and tertiary reference hospital in Switzerland.

Eligibility

We identified all patients between 01.01.2012 and 31.12.2017 that presented in the emergency department of Inselspital, University Hospital Bern (Switzerland), with trauma and neck pain. Of this population, we included all patients that required a radiographic c-spine evaluation according to the NEXUS criteria. We excluded all patients that presented at the pediatric emergency department and cases with incomplete medical records.

Search strategy and data extraction

We searched the "ecare" (electronic patient records) database of the emergency department of Inselspital, University Hospital Bern (Switzerland), for the terms "HWS-Fraktur + Distorsion + Schleudertrauma + Whiplash + Halswirbel" (translation "HWS-fracture + distorsion + whiplash (german) + Whiplash + cervical vertebrae"), also including partial matches. Patient cases identified by this method were reviewed for eligibility. Every case was reviewed by a certified spine surgeon (SFB) and a junior researcher (PA) trained by the senior authors (LMB, SFB, and CEA) and defined as injured or non-injured.

The data was extracted from the selected case files and imported into an Excel spreadsheet, anonymized and imported into R-studio (23,24) after the end of data collection. The observational period ended on 31.12.2018.

Variables

We manually extracted the following groups of variables (for a complete and detailed list see supplement S1):

(i) Patient demographics
(ii) Trauma mechanism
(iii) Imaging, radiologic findings, and orthopedic consults for X-Ray, LODOX, CT, MRI
(iv) Injury type
(v) Clinical Management

We assigned the trauma mechanism to either high- or low-energy trauma, and if more detailed information was available, to the exact class of mechanism (e.g., vehicle accident). High-energy included: exact mechanism unclear, car/motorcycle accidents >50 km/h, bicycle accident, fall from a great height (double body height), horseback fall, and alpine sport accidents. Low-energy included: exact mechanism unclear, vehicle accident <50 km/h, pedestrian struck, fall from less than three meters (less than ten stairs), minor trauma, assault, epileptic seizure, strangulation, object fell on the head, collision, body check, and head impact.

Statistical methods

Included patients were filtered on demographics, symptoms, imaging technique, injury, trauma mechanism, and the result of the surgical case review. Grouping and subgrouping were performed using the R package-collection "tidyverse" (25). The difference in number of presenting male and female patients was tested using the binomial test. We tested for a normal distribution of age in both male and female patients using the Shapiro-Wilk test. For both being not normal-distributed, we applied the Wilcoxon Rank-Sum test ($alpha = 0.05$) to test if there is a difference in the age at presentation between male and female patients. We assessed true/false positives and true/false negatives for each imaging modality by comparing the result of performed imaging to the decision of the spine surgeons' case review as a gold standard. Sensitivity and specificity (with 95% confidence intervals) were calculated using the package "epiR" (26). Receiver operating characteristic curves (ROC) were computed by fitting a binomial linear regression onto the respective results (e. g. CT) and the package "pROC" (27) was used for computing the ROC. We used a binomial logistic regression in patients that presented with low-energy trauma to predict injury using the patients' age as predictor. We then extracted the age threshold with maximum Youden-Index of the ROC curve calculated from this model.

Ethical considerations

The Swiss Human Research Act (HRA) regulates research involving humans in Switzerland. According to the HRA, anonymized data can be used for research purposes without the need for explicit consent or approval from an ethics committee, if the data are irreversibly anonymized and there is no risk of re-identification. For our study, we used only fully and irreversibly anonymized data, which is why no approval from the ethics committee was obtained.

Results

Participants

We identified 4996 patients who presented with neck pain and trauma in the database following our search strategy between 01.01.2012 and 31.12.2017.

According to NEXUS criteria, 2675 patients had no indication for imaging, thus, 2321 patients received a radiographic workup. In the included patient population, 2135 Patients were classified as uninjured and 186 as injured by a junior researcher and spine surgeon in the retrospective case review (Fig. 1).

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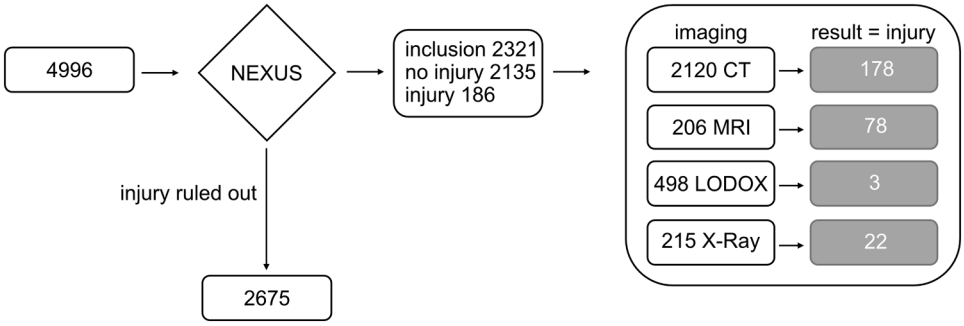

Fig. 1. | 4996 patients were identified through "ecare" database search. Of those, in 2675 patients, c-spine injury was ruled out by applying the NEXUS criteria and patients did not receive imaging. The remaining 2321 patients received imaging and were included in our analysis. The case review by spine surgeons marked 186 of these cases as injured and 2135 as uninjured. Imaging of included population was performed as shown. Several patients received multiple modalities of imaging. Pathologic imaging results are displayed on the right.

Descriptive population analysis

The most frequent nationality was Swiss (1,808), followed by German and Italian. The study population showed a larger proportion of men (1334, 57.5%) than women (987, 42.5%). The male participants presented at a significantly (p <0.001) younger median age (50 years, IQR 36) than the female participants (52 years, IQR 47). This both accounts for a peak between age 30 and 60, where men show an increased presentation with neck trauma and pain compared to females of the same age group (589 males vs 344 females between 30 and 60 years) (Table 1, Fig. 2). Most patients presented without any preexisting spine condition, however, the most abundant conditions were degenerative spine disorders (45.89%) and osteoporosis (5.82%) (Table 1, Supplement S2).

Low-energy traumas were more frequent (n = 1700, 73.2%) than high-energy traumas (n = 621, 26.8%). High-energy traumas were most frequently caused by bicycle and vehicle accidents (>50 km/h) whereas the most abundant known mechanism for low-energy traumas were falls from less than 3 m of height (S3).

Regarding mortality, 298 (12.8%) patients died until the end of follow-up (31.12.2018). In our cohort, 45 patients died in the first 10 days after the trauma. Of those, 16 died in the first 24 h (Table 1).

Table 1

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Demographic	Patient Count	
Sex		
Male	1334	(57.5%)
Female	987	(42.5%)
Age (years, median)	50	(IQR 39, range 15 - 101)
Male	50	(IQR 36, range 15 - 99)
Female	52	(IQR 47, range 16 - 101)
Decision of Case Review		
Injured	186	(8.0%)
Uninjured	2135	(92.0%)
BMI (kg/m^2, median)	24.4	(IQR 5.3)
Male	24.7	(IQR 4.9)
Female	23.4	(IQR 5.1)
Preexisting Spine Condition		% of all patients
None	1222	(52.7%)
Degenerative Changes	1065	(45.9%)
Osteoporosis	135	(5.8%)
Trauma		% of all patients
High-energy	621	(26.8%)
Low-energy	1700	(73.2%)
Death		% of all patients
during follow-up	298	(12.8%)
within 10 days	45	(1.0%)
within 48 h	19	(0.8%)
within 24 h	13	(0.5%)
Nationality		
75 different nationalities	1808	(77.9%)
Swiss	71	(3.1%)
German	41	(1.8%)
Italian		

Outcome diagnostics

We included 2321 patients, encompassing 2120 CT scans, 498 LODOX scans, 206 MRI scans, and 215 X-ray examinations conducted in the emergency. These imaging techniques resulted in 178 positive CTs (8.4%) 3 positive LODOX scans (6.02%), 22 positive X-rays (10.2%), and 79 positive MRI findings (38.4%) (Fig. 1).

Main results

We compared the imaging results to the case review of the spine surgeon specialists' decision to assess for true positive/negative results. For CT imaging, sensitivity (88.6%) and specificity (99%) were high. Additionally including the consult of an orthopedic surgeon in the diagnostic pathway had a sensitivity of 89.8% (specificity 99.2%). This was comparable to the sensitivity (88.5%) and specificity (96.9%) of the performed MRI.

For 14 patients that showed false negative in CT imaging, MRI did uncover an injury (7.5% of all injured participants). Based on the MRI diagnosis, six of this patient subset underwent surgery.

LODOX offers a fast and effective method to assess severely injured patients in the trauma unit (28). We found a low sensitivity (5.3%) but a high specificity (100%).

The plain radiograph had a sensitivity of 36.4% and a specificity of 95.1% (Table 2). Injured patients that were examined using both, CT and projection radiography, were correctly diagnosed (sensitivity 100%, specificity 97.1%) (Table 2, Fig. 3A).

Age as an independent risk factor

By fitting a logistic regression to age and the case-review decision, in the low-energy trauma cohort (n = 1700) the maximum Youden's J was 0.14 for age predicting injured vs. non-injured at 64.5 years. This threshold had a sensitivity of 51.85% and a specificity of 61.81% (AUC of ROC 0.58, 95% CI 0.52 - 0.63) for determining spinal injury (Fig. 3B). Over all patients, the best threshold was at 42.5 years.

Regarding the age threshold of 65 years defined in the NEXUS criteria, in our cohort, 10.1% of the patients aged 65 years (81 of 753) and older were injured and only 7.0% (105 of 1568) of the patients under the age of 65.

Injury localization

Injuries can be categorized into mono- and multi-segmental injuries. Mono-segmental injuries made up 57.5% (107 patients) were located in C1, C2, and increasingly frequent in the lower cervical spine, being highest in C7. Multi-segmental injuries (42.5%, 79 patients) mostly involved C5 and the middle part of the cervical spine (Fig. 4A).

We examined the false negative results by grouping the mono- and multi-segmental injuries by imaging technique, to determine which injuries were more likely to be missed. In CT and MRI, only few injuries were missed. These were mostly located in the middle c-spine. In

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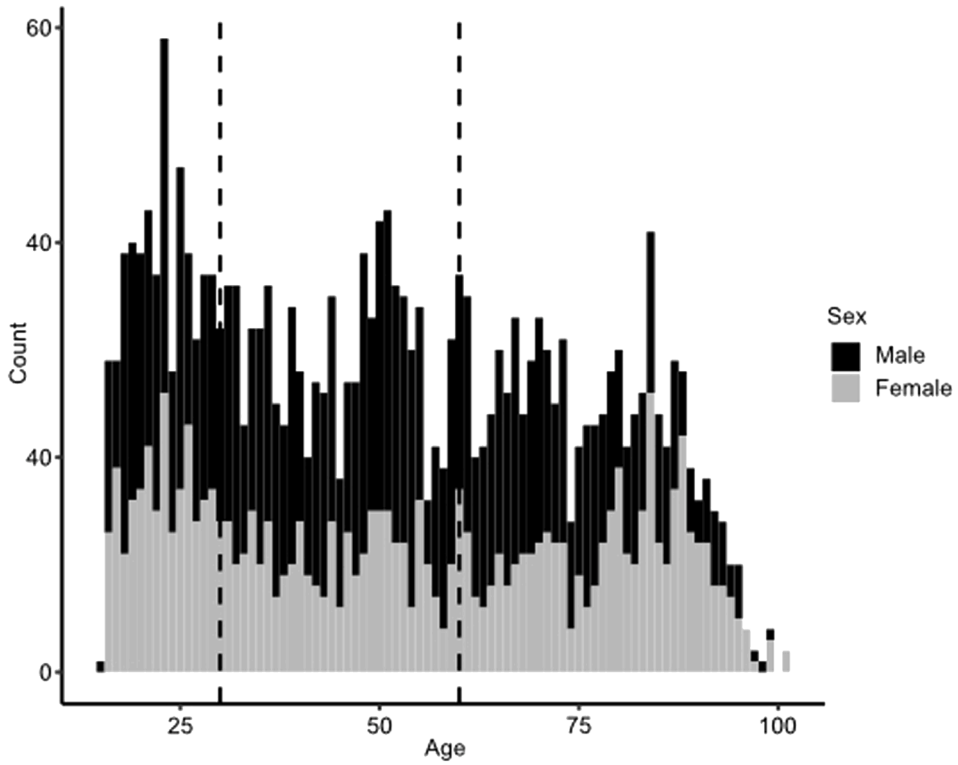

Fig. 2. | Women show an almost equal distribution of neck trauma throughout their lifetime. Men experienced an additional peak of neck trauma between the age of 30 to 60 (dashed lines) and presented at a significantly younger age than women ($p < 0.001$, male: median 50 years IQR 36, female: median 52 years, IQR 47).

Table 2
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Imaging Modality	Sensitivity (95% CI)	Specificity (95% CI)	AUC (95% CI)
CT in ED ($n = 2120$)	0.886 (0.830 - 0.929)	0.990 (0.984 - 0.994)	0.938 (0.914 - 0.962)
CT in ED ($n = 2120$) and orthopedic consult ($n = 78$ of 2120)	0.898 (0.844 - 0.939)	0.992 (0.987 - 0.996)	0.945 (0.923 - 0.968)
LODOX ($n = 498$)	0.053 (0.011 - 0.146)	1 (0.992 - 1)	0.527 (0.497 - 0.556)
MRI ($n = 206$)	0.885 (0.792 - 0.946)	0.969 (0.922 - 0.991)	0.927 (0.888 - 0.965)
X-Ray ($n = 215$)	0.364 (0.204 - 0.549)	0.951 (0.908 - 0.977)	0.657 (0.572 - 0.742)
CT + X-Ray ($n = 49$)	1 (0.782 - 1)	0.971 (0.847 - 0.999)	0.985 (0.957 - 1)

projection radiography, false negative results of mono-segmental injuries were more frequent in the lower cervical spine. Multi-segmental injuries were diagnosed false negative by plain radiograph most frequently in the middle spine. This mirrors their more frequent occurrence in the central cervical spine. LODOX resulted false negative in all mono-segmental injuries. In multi-segmental injuries, LODOX resulted in a lower false negative rate in the middle c-spine (Fig. 4B).

Neurologic symptoms

The majority of patients presented with an inconspicuous neurological status. Of those who presented with neurological symptoms, 25 showed sensoric and 30 combined sensomotoric symptoms. However, 24% of sensoric and 10% of sensomotoric symptoms were not caused by a traumatic injury that correlated to a finding in the diagnostics. These patients suffered from neurological deficits not resulting from a traumatic c-spine injury (i.e., plexus lesion, transient fully reversible hyposensitivity).

Time management

Most injured patients did not require surgery. In total, 70 patients underwent spine surgery as a trauma consequence. Within the first 24 h, 45 patients went into surgery, 23 (51.11%) of which had neurological symptoms (S4). Five out of six patients with false negative CT that had a positive MRI finding and underwent surgery showed neurological symptoms.

Discussion

We present a large and detailed consecutive patient collective referred with neck pain and trauma at our level 1 trauma center. We determine the necessity for radiographic evaluation of the cervical spine using NEXUS criteria.

The study population includes more men (57%) than women. This reflects the overrepresentation of men aged 30 to 60 years due to high-risk behavior (29).

Extensive imaging is performed to identify a comparably small proportion of injured patients. In our study, less than 10% of CT scans revealed a c-spine injury in patients that were not ruled out by the NEXUS criteria. This also reflects the daily clinical practice, that in patients with neck trauma, the attending physicians are more inclined to request CT imaging.

By including the spine surgeons' case review of each patient file, we were able to deduct the sensitivity and specificity of our diagnostic algorithm.

Plain radiograph has shown to be an inefficient method (30) to evaluate the c-spine with poor sensitivity to detect injuries (31) which is even lower in our cohort than previously reported (31,32). We recommend not choosing plain radiographs to rule out an injury to the c-spine

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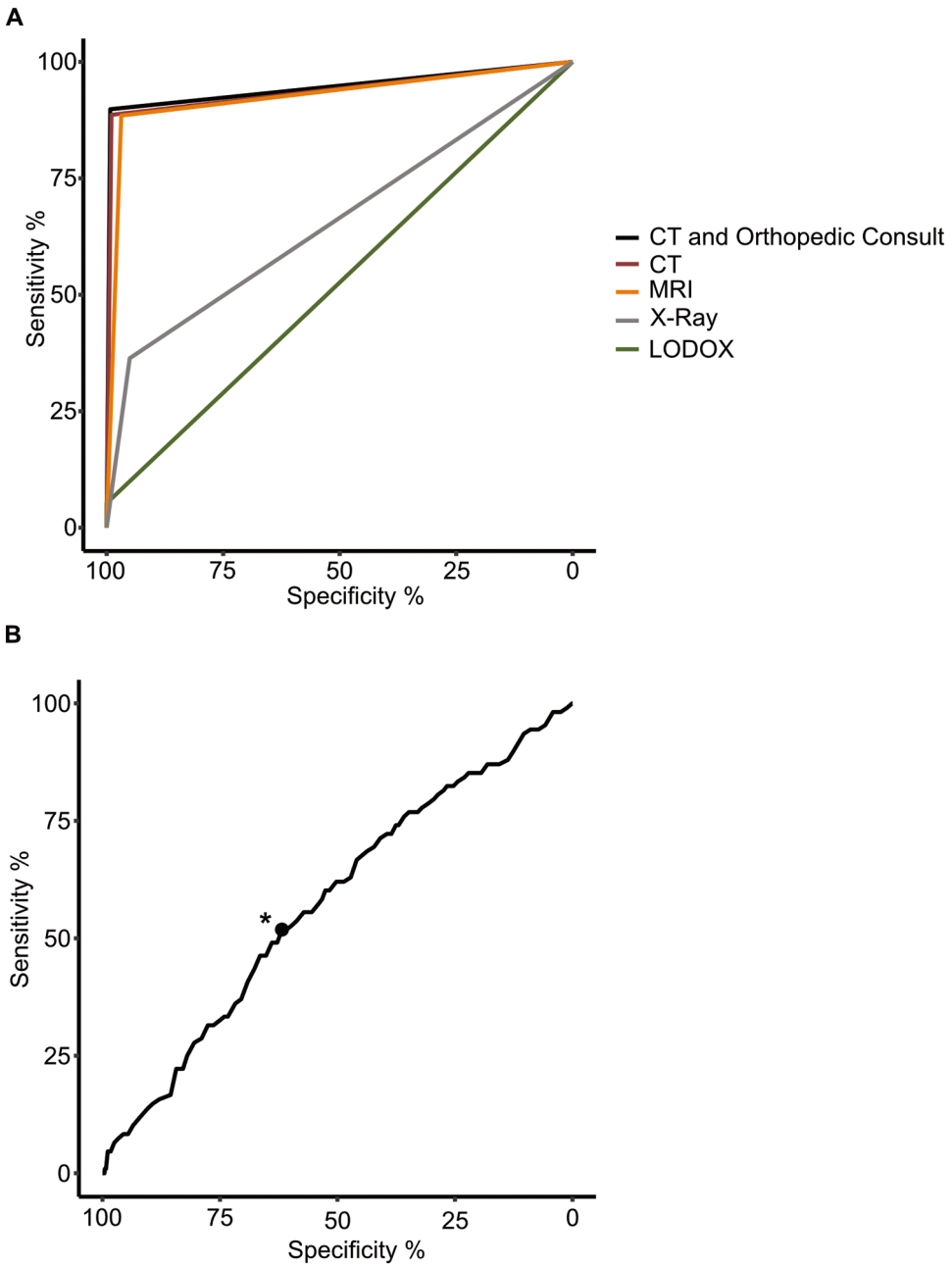

Fig. 3. | **A** The ROC demonstrates similar sensitivity and specificity of CT, MRI, and CT with an orthopedic consult. The AUC of X-Ray and LODOX is smaller than of the tomographic imaging methods. **B** Logistic regression analysis of patients that suffered a low-energy trauma reveals 64.5 years (sensitivity 51.85%, specificity 61.81%, AUC 0.575, 95% CI 0.523 - 0.631) as the threshold (*) with highest Youden's Index (0.14) for distinguishing injured vs. non-injured based on the patient`s age.

since in our cohort nearly two out of three injuries would have been missed. The plain radiograph has its value in our daily routine to determine the stability of fractures detected in CT scans.

The sensitivity of CT scans was 88.6% (specificity 99.0%) and could only be slightly improved by consulting an orthopedic specialist, showing that in only a few cases secondary expert knowledge is required for correct patient diagnosis. Moreover, the sensitivity of the CT matched the more time-consuming MRI (sensitivity 88.5%, specificity 92.7%) (Table 2). Duane and colleagues (22) conducted a large study including more than 9000 participants, in which MRI did not uncover any missed cervical injuries that lead to a therapeutic consequence. We demonstrate, that a negative CT does not completely rule out a c-spine injury with full certainty. Moreover, in 14 cases, our comparably smaller dataset includes patients that were diagnosed correctly by MRI although having a (false) negative CT scan. In six of these cases, MRI substantially changed the course of treatment and indicated surgery for those patients. While patients treated conservatively did not show any neurologic abnormalities, five out of six patients who underwent surgery showed neurologic symptoms. Although not a judicious recommendation for c-spine injury patients, we demonstrate that MRI holds its value in the diagnostic of complex patients with negative CT scans. Especially patients presenting with any neurologic deficit and a negative CT scan benefit from a fast MRI. In clinical practice, time has proven to be a key prognostic factor in spinal injury in emergency medicine (33). In our cohort, 51.11% of patients who had surgery within 24 h presented with neurological symptoms, stressing the therapeutic importance of correctly diagnosing patients with neurologic symptoms.

Our analysis demonstrated that C1, C2, and the lower part of the

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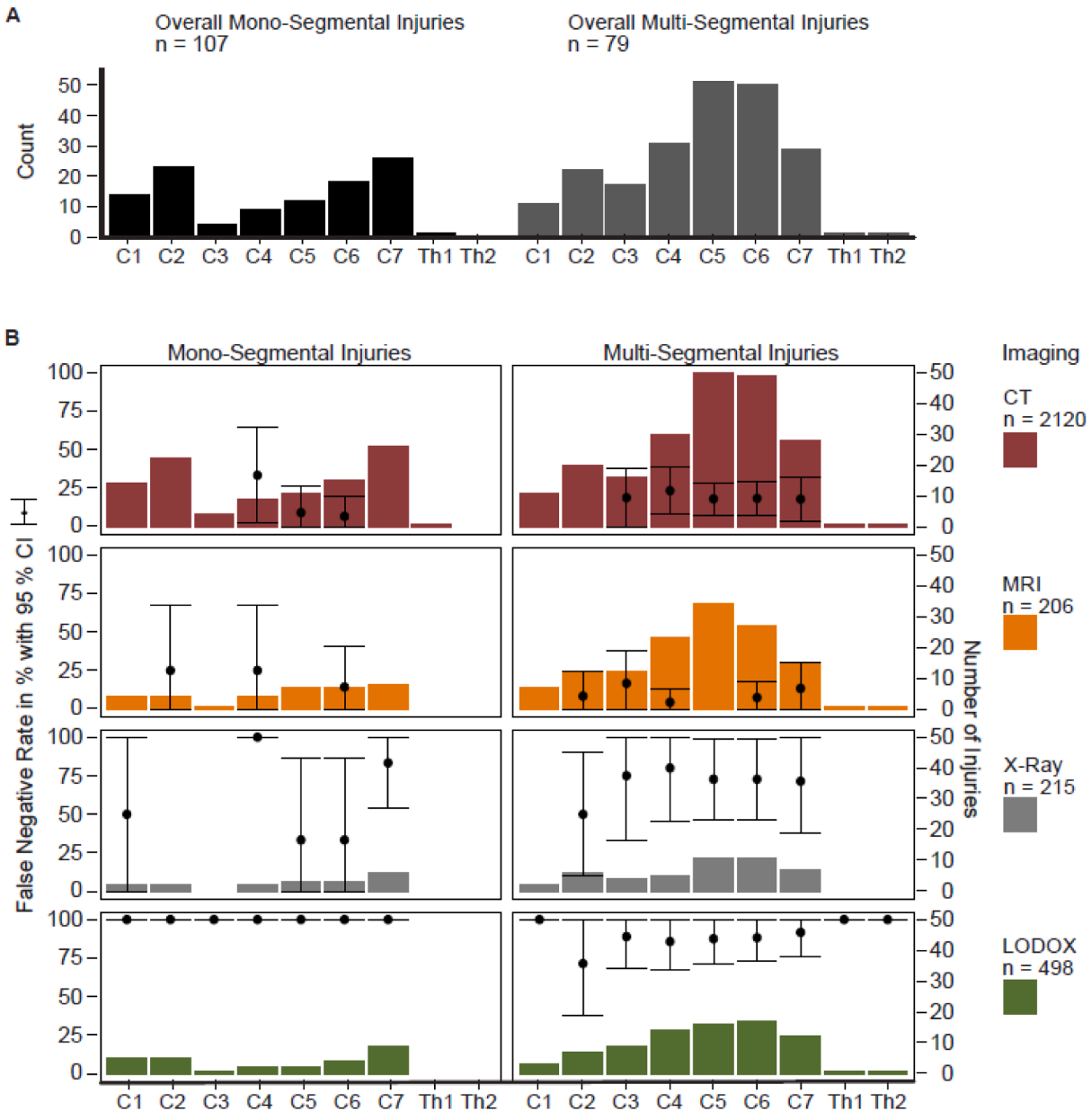

Fig. 4. | **A** Mono-segmental injuries have a bimodal distribution at the mobile junctions of the c-spine. Multisegmental injuries are most frequent in the middle part of the c-spine, with C5 involved most often. **B** The bar plots represent the number of patients with a specific segmental injury (right Y-axis) for each imaging modality (CT, MRI, X-Ray, LODOX). The dot plot depicts the false negative rate (left Y-axis) for each imaging method at each segment. The error bars represent the 95% confidence interval.

spine were prone to false negative diagnostic results, especially in plain radiographs. We emphasize to pay special attention to these regions and consider choosing CT or MRI when in suspicion of injury. Moreover, with 42.5% multi-segmental injuries our study is higher than the clinical assumption(9), stressing the importance of searching for multiple fractures when encountering a single fracture in imaging.

This study`s cohort validates the actuality of the NEXUS criteria`s cutoff of 65 years. In our model, 64.5 years is the best threshold for patients in low-energy trauma, only regarding age as an independent risk factor. We therefore again emphasize the NEXUS guidelines and recommend generous imaging by CT or MRI in the population of 65 years and above.

Strengths

The strengths of this study lie in its robust methodology and clinically relevant findings. Firstly, our large sample size, encompassing 4996 patients, ensures a comprehensive analysis of the performance of various imaging techniques in diagnosing cervical spine injury. Moreover, the real-world setting of this study, derived from a level 1 trauma center's emergency department, enhances the external validity and applicability of our results in diverse clinical scenarios. Our evaluation of multiple imaging modalities, including CT, MRI, LODOX, and X-Ray, provides valuable comparative insights for clinical decision-making, while the expert review of cases by certified spine surgeons guarantees a high level of expertise in injury classification and imaging assessment. Additionally, the use of the widely accepted and clinically relevant NEXUS criteria for patient inclusion underscores the practical significance of our findings. This study also highlights the importance of MRI in detecting injuries not identified by CT scans in symptomatic patients, offering a valuable contribution to the understanding of MRI's role in cervical spine injury diagnosis. Moreover, this study is first to evaluate

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LODOX-Statscan in diagnosis fo c-spine injury. Finally, our results emphasize the benefits of interdisciplinary collaboration, demonstrating that orthopedic consultation in the emergency department can further improve the sensitivity and specificity of CT scans for spinal injury detection.

Limitations

Despite its notable strengths, this study has certain limitations that warrant consideration. Primarily, the retrospective monocenter design, based on data from a single trauma center, may influence the generalizability of our findings, as they could be affected by local practices and patient population characteristics. However, the large sample size and real-world setting partially mitigate this limitation. Additionally, while sensitivities and specificities were calculated for each imaging method, the study lacks a direct comparison of these techniques in the same patients, which could limit the conclusions about their relative performance. Although a large number of patients were included and a large amount of imaging was performed, only a small proportion (8.0%) of the included population actually suffered from a cervical spine injury. This reduces this study's power to add clinical predictors to the NEXUS criteria. Moreover, CT was the most commonly used modality and other imaging techniques were applied less frequently. We included different CT scan protocols as the trauma spiral CT and explicit cervical spine CT. Lastly, information on patient follow-up and the long-term impact of missed or misdiagnosed injuries is not provided, restricting our understanding of the clinical significance of the identified/missed injuries. Despite these limitations, our study offers valuable insights into the performance of various imaging modalities in diagnosing cervical spine injury and emphasizes the importance of interdisciplinary collaboration in patient management.

Conclusion

This study represents a large patient cohort presenting with neck pain and trauma. We demonstrated, that although not being ruled out by the NEXUS criteria, only a few patients suffer a from traumatic cervical spine injury. CT performed best in identifying c-spine injury, regarding sensitivity and specificity, and is comparable to MRI. We do not recommend plain radiography to rule out suspected c-spine injury. Patients with neurological symptoms should be paid special respect, especially when CT results turn out normal. In this particular case, we recommend the generous execution of an MRI to diagnose c-spine injury correctly.

Declaration of Competing Interest

NR, PA, AKE, SFB, and CEA declare no interests. LMB receives consulting fees by Icotec and Kuros, which are paid to institution, and is board member at Sentryx, which is paid to institution. LMB is member of AOSpine and SwissOrthopedics. FS receives institutional funding by the Swiss National Science Foundation unrelated to the underlying manuscript. FS has received honoraria and travel expenses by Geistlich Pharma AG. MM receives the Swiss Heart Foundation Research Grant (2022), International Emergency Care Foundation Grant (2022) and Summer-School on Refugee and Migrant Health - research grant from Burgergemeinde (2022).

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.injury.2023.05.003.

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